RESEARCH DEPARTMENT

Subjective tests on simulated line - store standards conversion with interpolation

RESEARCH REPORT No. T-128

1964/46

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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SUBJECTIVE TESTS ON SIMULATED LINE-STORE STANDARDS CONVERSION WITH INTERPOLATION

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SUMMARY

This report describes tests on the subjective acceptability of television pictures produced by a line-store standards converter that incorporates interpolation between adjacent lines of the input video signal. A brief description of the experimental procedure and apparatus is given. Two basic forms of interpolation, together with one of composite nature, were tested and their relative merits were compared by means of subjective tests.

The results of the subjective tests are presented in the form of histograms.

1. INTRODUCTION

A line-store standards converter does not utilize the intermediate optical image that is found in the more conventional form of converter. Instead, the input video signal is split up into samples, corresponding to individual picture elements, which are fed into a series of suitable stores and subsequently extracted according to a time scale appropriate to the output scanning standard.

Simulation experiments[1] have shown that the output picture resulting from such a converter is subjectively displeasing if the change in the number of scanning lines is accomplished solely by rejecting or repeating some of the scanning lines of the incoming video signal.

The process of interpolating between adjacent input lines can, theoretically, provide a more acceptable output signal. The tests described in this report were designed to study the subjective merits of various interpolating processes that are instrumentally convenient.

Since a line-store standards converter of a suitable form was not available, these tests employed the technique for simulating the effects of a converter which has been described in an earlier report.[1] A line-delay interpolator[2] was built and interposed between a 625-line picture source and the picture display. By perturbing the vertical scan of the display so as to simulate a 417-line picture and by supplying various interpolating waveforms to the control circuits of the interpolator, the required subjective results were readily obtained.

Since the technique of video interpolation is comparatively new, it is discussed more fully in Section 2.

2. INTERPOLATION

2.1. General

One of the most unpleasant spurious effects observable in the picture from a line-store converter without an interpolator, or a valid simulation of such an arrangement, is a 'sawtooth' effect on sloping picture features. This occurs because, in general, scanning lines of the input standard do not traverse the same strip of picture area as lines of the output standard; picture information that is transferred from an input line to an output line may be incorrectly reproduced in the vertical direction. This positional error varies from line to line, resulting in an obvious distortion.

This effect is illustrated in Fig. 1, which shows an inclined row of picture points (A, B, C, etc.) that represent the sloping edge of a televised object. In this example, the conversion involves reducing the number of lines per field by a factor of 3/4 and the basic process of conversion has been carried out simply by rejecting every fourth line of each input field, together with all the information it

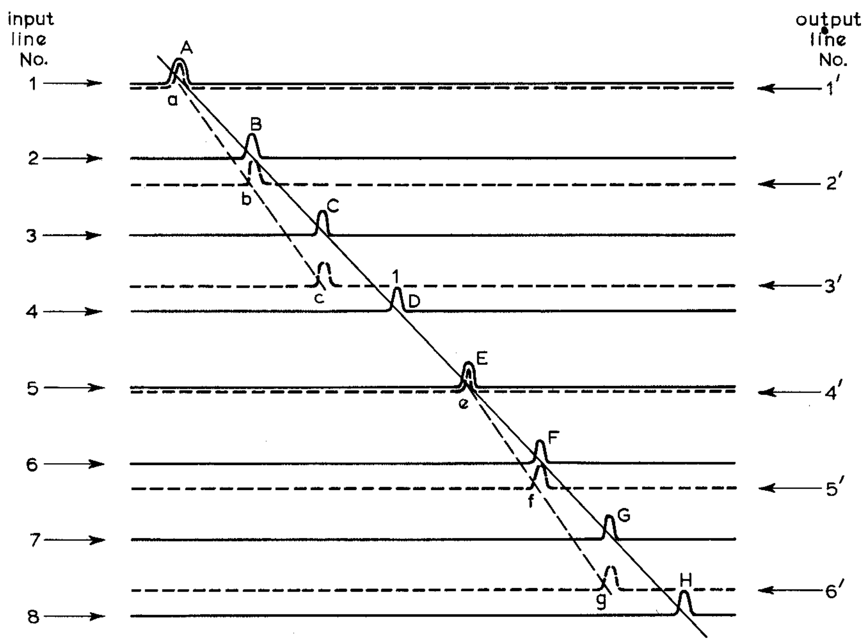

Fig. 1 - Simulation of conversion from a higher number of lines per picture to a lower number without interpolation

Input line waveform with picture point

Output line waveform with picture point derived from input

1, 2, 3, Input line numbers

1', 2', 3', Output line numbers

contains, and uniformly redistributing the remainder in the vertical direction. This has caused picture point A on input line 1 to be reproduced at 'a' on output line 1', B at 'b', and point C at 'c' and, as every fourth input line has been rejected, the point D has been eliminated. The points E,F,G,H have been treated similarly. In the output picture, the resulting geometrical distortion, in the form of the sawtooth appearance of sloping edges, can be clearly seen.

Interpolation is a means of 'reading between the lines' of the input standard in an attempt to provide correct brightness information for those lines of the output standard which lie between the input lines. Each output line that does not coincide with an input line is supplied with video information derived from a suitably weighted sum of the signals from two adjacent input lines. This process is shown in Fig. 2. As in Fig. 1, point A on input line 1 is reproduced at the coincident point 'a' on output line 1'. However, output line 2' lies between input lines 2 and 3, and points B and C are reproduced at 'b_1' and 'c_1' respectively, the amplitudes of the signals representing 'b_1' and 'c_1' being related to the distances Bb_1 and Cc_1. Similarly output line 3' includes contributions 'c_2' and 'd_1' for C and D. The effect of this is to reduce subjectively the geometric distortion resulting from the vertical displacement of some picture elements, at the cost of a slight reduction in the sharpness of the sloping edge.

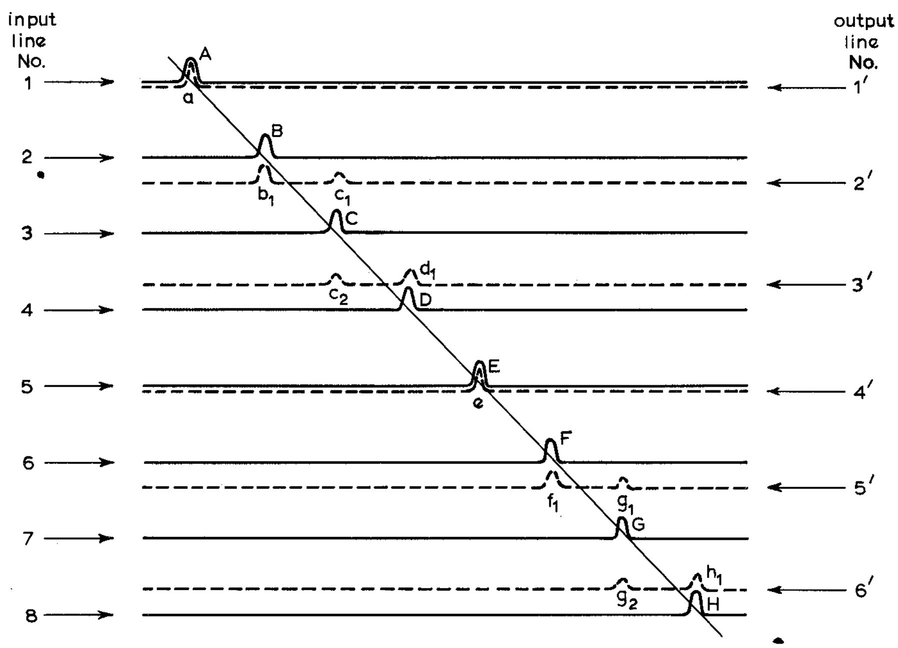

Fig. 2 - Simulation of conversion from a higher number of lines per picture to a lower number with interpolation

	Input line waveform with picture point
	Output line waveform with picture point derived from input
1, 2, 3,	Input line numbers
1', 2', 3',	Output line numbers

The law defining the relationship between the magnitudes of the signal contributions from adjacent input lines of a field to any given output line and the distances of the output line from the corresponding input lines is known as 'the interpolation law'. It is desirable to choose this law so as to give the maximum possible reduction in spurious effects with the minimum reduction in picture sharpness.

It has been shown[3] that interpolation can be regarded as an 'operator' upon the vertical spectrum* of the incoming television picture and may be expressed in terms of the response as a function of vertical spatial frequency: the ratio of the modified vertical spectrum to the original vertical spectrum. Since the spurious effects mentioned earlier can be considered as a beat pattern between the input and output line structures, they may be effectively reduced by using an equivalent line profile whose response, as a function of vertical spatial frequency, has a zero at the input line frequency and reduced even further if the response has zeros at both the input and output line frequencies; however, the vertical resolution must not be degraded too severely.

One suitable response as a function of vertical spatial frequency may be described in terms of a normalised variable $f.T_I$, by:

$$g(f.T_I) = T_I \cdot \frac{\sin 2\pi f T_I}{2\pi f T_I \, (1 - 4f^2 T_I^{\,2})} \qquad (1)$$

where f denotes frequency and T_I is the duration of one input scanning line.

Such a response corresponds to a cosine-squared line profile whose half-magnitude width is equal to the spacing between adjacent lines of an input field. More complete information concerning suitable responses, as functions of vertical spatial frequency, and the corresponding line profiles is given in References 2 and 3.

In the tests, the following line profiles (or interpolating apertures) were used:

(i) a rectangular profile (zero-order interpolating aperture) having a width equal to the spacing between adjacent lines of an input field. This is, in fact, no interpolation[1] and corresponds to a response, as a function of vertical spatial frequency of the form:

$$g(f.T_I) = \frac{\sin \pi f T_I}{\pi f T_I} \qquad (2)$$

(ii) a cosine-squared line profile corresponding to the response defined in equation 1, and

*The Fourier transform of brightness as a function of position along a vertical strip of the image.

(iii) a combination of the cosine-squared profile (ii) with a rectangular profile having a width corresponding to the spacing between alternate lines of an input field; by adding suitable proportions of the corresponding responses the resulting response has zeros at both input and output line-scan frequencies (see Appendix).

2.2. The line-delay interpolator

In a practical interpolator, it is necessary to be able to mix together continuously variable proportions of the signals representing two adjacent input lines. This process can be expressed in the form of an equation:

$$e = Se_1 + (1 - S)e_2 \quad (3)$$

where e is the required signal and e_1 and e_2 are the signals representing the two adjacent lines; S is the interpolating function and has any value between 0 and 1.

It is obviously essential to have access to e_1 and e_2 simultaneously and since they occur one input line period apart in time, it is necessary to provide a means for delaying the video signal by a line-scan period. The interpolating function S is repetitive at the difference between the input and output line frequencies and its waveform is determined by the chosen interpolation law. S determines the proportions in which the signals e_1 and e_2 are mixed and the extreme values (0 and 1) occur when the whole of the output signal is derived wholly from the input or output of the delay device, and represent coincidence of input and output lines (e.g. lines 1 and 1' of Fig. 2).

A block diagram of an interpolator operating in accordance with equation 3 is shown in Fig. 3. The correct operation of such an interpolator depends on the accuracy and balance of two matched modulators. Simple algebra shows that the same result can be achieved with only one modulator and that the modulator now varies the

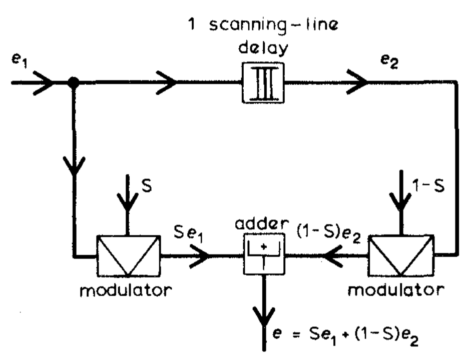

Fig. 3 - Subjective tests on standards conversion with interpolation. Line-delay interpolator (2 modulators)

e Output signal
e_1 Input signal
e_2 Delayed input signal
S Interpolation Function

magnitude of a signal representing the difference in the information carried by adjacent television lines of the same field, so that any shortcomings in the modulator do not disturb the picture in areas where there are no horizontal or sloping edges.

Equation 3 may be re-written:

$$e = S(e_1 - e_2) + e_2 \qquad (4)$$

Thus it is necessary to modulate only one function $(e_1 - e_2)$ by one interpolating function S and add this resultant to the delayed signal. It is important to note that the interpolating function S is exactly the same as in the two-modulator interpolator, and still represents the proportions in which the signals representing the two adjacent television lines are to be mixed. Such an interpolator is shown in Fig. 4.

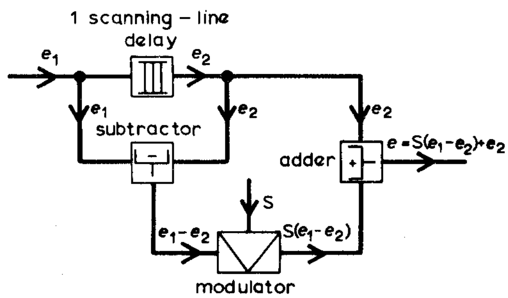

Fig. 4 - Subjective tests on standards conversion with interpolation. Line-delay interpolator (1 modulator)

e Output signal
e_1 Input signal
e_2 Delayed input signal
S Interpolation Function

The forms of interpolator described can only be used when simulating conversion from a higher to a lower number of lines. If there were more output lines than input lines per field, it would be necessary to utilize, in the interpolator, the signals representing some input lines more than twice. Further, different values of the interpolation function would, in general, be used for these signals. This means that the signals corresponding to any given pair of lines would have to be simultaneously available more than once. This would involve the use of further delay.

2.3. Simulated standards conversion with interpolation

In one embodiment of the technique for simulating line-store standards conversion[1] the reduction in the number of lines assumed in the simulation is achieved by 'blacking-out' a number of selected lines at the display and uniformly redistributing the remaining lines by perturbing the vertical scan of the display. The resulting scanning pattern then has the same subjective appearance as a normal raster and each

line of picture represents a line that would be extracted from the store of a line-store converter.

Since all the original picture information is available at the input, the process of interpolation when interposed between the picture source and the display can provide each of the scanning lines that is not blacked-out with a properly proportioned sum of the video signals from two consecutive input line periods, even if one of these two line periods is coincident with black-out of the display. Since the displayed scanning pattern is subjectively indistinguishable from a normal scanning raster and the video signal applied to each line is interpolated exactly as it would have been in a real conversion, this technique is valid for the subjective appraisal of interpolation.

3. DETAILS OF THE EXPERIMENTS

3.1. Apparatus

A block diagram of the complete apparatus used is shown in Fig. 5.

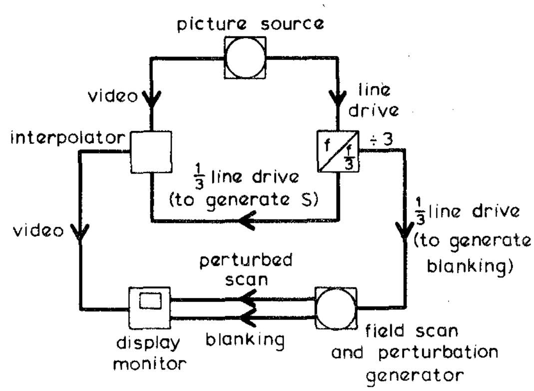

Fig. 5 - Subjective tests on standards conversion with interpolation (625 lines to 417 lines). Complete apparatus

The interpolator employed a delay unit of the type in which the video signal to be delayed amplitude modulates a carrier (at about 15 Mc/s) and the resulting signal is then propagated through mercury as an ultrasonic wave.[4] The modulator that varied the amplitude of the video difference signal, derived by subtracting the delayed input signal from the undelayed input signal, utilized a Hall Plate.[5] This consisted of a thin square plate of Indium Arsenide, to which the video difference signal was applied across two opposite sides. The plate was located in the field of an electro-magnet whose energising current was made proportional to the value of the interpolating function; thus the output appearing across the other two sides of the plate was proportional to the product of the magnitudes of the magnetic field and the applied signal. The inductance of the electro-magnet winding was about 20 mH and the cosine-squared current waveform representing the interpolation-function was obtained by resonating the inductance to half the input line frequency and driving it with a current pulse having a 2 : 1 mark/space ratio and a repetition period of three

input line periods. Fig. 6 shows the principle of operation of the circuit. With

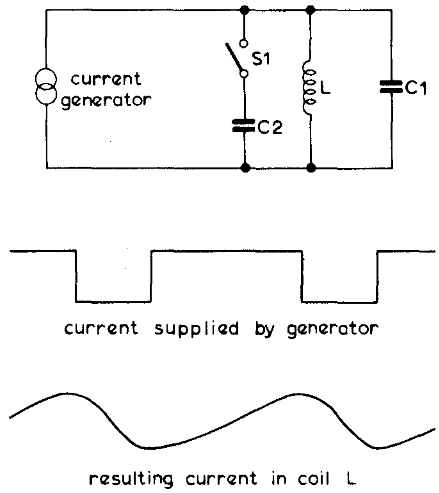

Fig. 6 - Subjective tests on standards conversion with interpolation. Operation of interpolation law generator

S_1 open, L and C_1 were arranged to resonate at half the input line frequency. With S_1 closed, L and $(C_1 + C_2)$ were arranged to resonate at one quarter of the input line frequency. Switch S_1 was operated synchronously with the applied current and the resulting current in the inductance was of the form shown; each section of the waveform was a half cycle of a cosine-wave. The circuit is similar in operation to a typical line-scan output stage.[6]

If a two-modulator interpolator were being used, the modification of the cosine-squared interpolation law in order to provide the third form of interpolation mentioned in Section 2.1 requires the addition to the output signal of a small fixed amount of both e_1 end e_2 (from Equation 3). This can be achieved by adding a d.c. component to the control signals of the two modulators. Bearing in mind that the interpolation function required for the single modulator version of the interpolator is exactly the same as that for two modulators, a constant amount of difference signal must be added to the output signal and equation 4 becomes modified thus:

$$e = \frac{1 - k}{1 + k} \left\{S(e_1 - e_2) + e_2\right\} + \frac{k}{1 + k} (e_1 + e_2) \qquad (5)$$

where k is a coefficient determining the relative proportions of the cosine-squared and rectangular profiles, (see Appendix).

3.2. Subjective tests

Six observers, all of whom were television engineers, were seated at approximately five times picture height from a 21 in. (53 cm) monitor displaying the simulated 625-to-417 line conversion. The brightness of the tube screen for zero beam current was about 1 ft-L (17 asb) and the picture white brightness was about 20 ft-L (215 asb). Using a suitable picture, the observers were first given a demonstration of the relatively gross picture impairment produced when simulating conversion without

interpolation. They were then asked to grade the impairment of various pictures under the three interpolation conditions mentioned in Section 2.1.

Namely:

(i) without interpolation,

(ii) with interpolation corresponding to a cosine-squared line profile, and

(iii) with composite interpolation corresponding to the combination of a cosine-squared profile with a two-line rectangular profile.

The following grading scale was used:

Grade 1 Imperceptible

Grade 2 Just perceptible

Grade 3 Definitely perceptible but not disturbing

Grade 4 Somewhat disturbing

Grade 5 Very disturbing

Grade 6 Unusable

Using each type of interpolation in turn the observers were shown pictures derived from motion picture film, still slides and slides that were moved vertically in an approximately sinusoidal manner. One cycle of slide movement occupied about 2 seconds and the peak displacement approximated to 1/20th of picture height. The observers were also asked to grade normal 405-line pictures derived from a moving slide; when the slide was moved vertically, the interlace 'twinkle' was found subjectively to be very similar to one of the effects resulting from the simulated conversion and was, in fact, assumed by some observers to be the same effect.

4. RESULTS

The results are shown in Fig. 7 in the form of histograms. In each histogram the percentage of votes for each subjective grade is plotted as a function of grade; the mean subjective grade is also given.

From the results for still slides and film, it will be seen that, with rectangular interpolation, the most favoured grades were 'somewhat disturbing' and 'very disturbing' respectively, the mean grades being 3·7 and 4·2. Cosine-squared interpolation, however, improved these mean grades to 2·0 ('just perceptible') while composite interpolation made a further improvement to give grades of 1·9 and 1·2; this means that the impairment was 'imperceptible' to at least some of the viewers.

The results obtained for moving slides include, for comparison purposes, those obtained for normal 405-line pictures, as mentioned earlier. For simulated

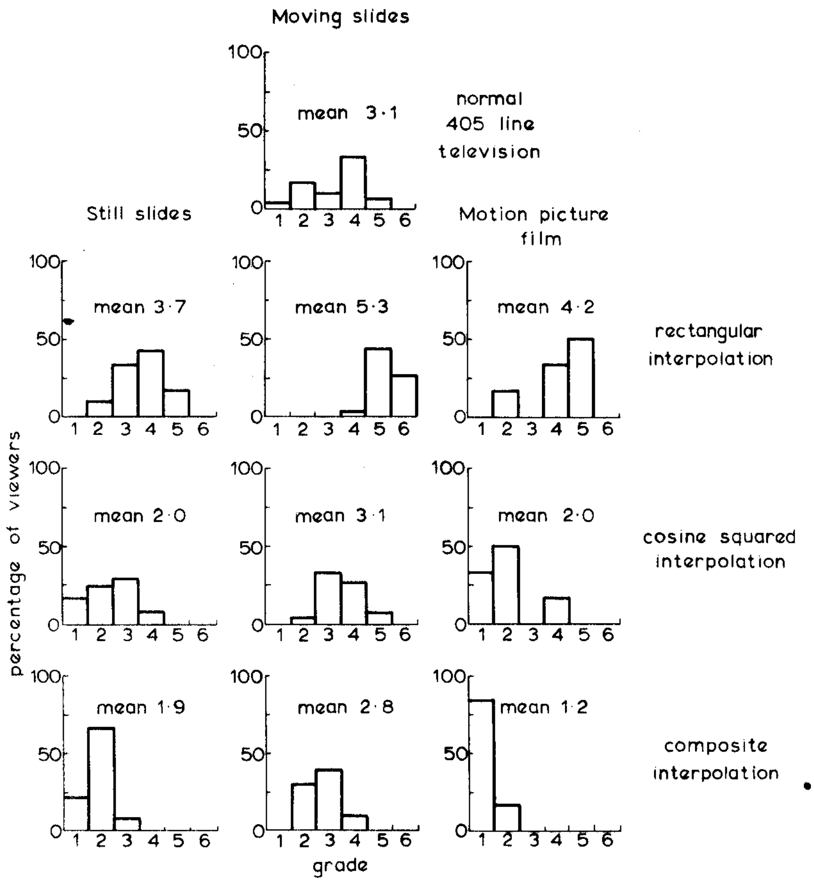

Fig. 7 - Subjective tests on standards conversion with interpolation. Separate results for still slides, moving slides and motion picture film

conversion with moving slides, the best mean grading obtained was 2·8, again with composite interpolation, and it is interesting to note that the pictures resulting from the simulated conversion were judged to be slightly less impaired than the normal 405-line pictures.

The overall results comparing the three forms of interpolation, taking all types of picture into account, are shown in Fig. 8.

5. AN ALTERNATIVE METHOD OF INTERPOLATION

Since the completion of the tests just described work has led to the concept of 'parallel-interpolation'.[7] Normal interpolation assumes that the lines of two superimposed rasters, corresponding to the input and output standards respectively would be at a slight angle to each other. This means that the vertical position of a given output line, relative to the two adjacent input lines, will vary with horizontal position. This, in turn, means that the interpolation law must vary during an input line period. If, however, the output raster were to be rotated by about 0·07° (for a 625 to 405 conversion) so that the two sets of scanning lines were

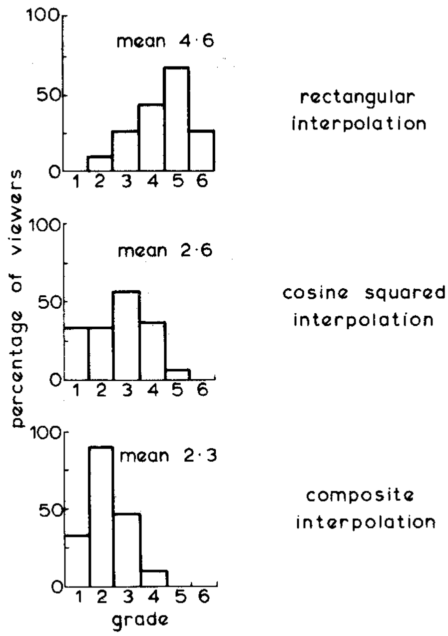

Fig. 8 - Subjective tests on standards conversion with interpolation. Overall results

made parallel, the interpolation law would be constant throughout one line period. This is instrumentally advantageous in the manufacture of a real converter as it allows the writing system to be arranged so as to write into the stores only those lines that are to be extracted, and makes it possible to avoid coincidence of the reading and writing processes at a store unit. This type of interpolation is subjectively indistinguishable from normal interpolation since the admixture of adjacent-line signals is determined by the same interpolation law and the relative positions of the two rasters may be chosen suitably.

6. CONCLUSION

The results would indicate that both cosine-squared and composite interpolation can give pictures whose mean grading is less than 'definitely perceptible but not disturbing'. Composite interpolation results in an impairment that is about 0·3 of a grade less than that given by cosine-squared interpolation and is, therefore, to be preferred. Interpolation of the composite form largely overcomes the difficulty of providing satisfactory pictures from a line-store converter using capacitor stores. The results lead to the conclusion that, except for some inevitable loss of vertical resolution, the picture quality from a line-store converter can approach that of 'direct' television.

7. REFERENCES

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APPENDIX

The Modification of Cosine-squared Interpolation to Produce a Zero at Output Line Frequency in the Vertical Spectrum of the Output

This appendix is based on the work of Mr. G.D. Monteath who suggested the composite interpolation waveform.

The process of interpolation applied to a line-store standards converter is analogous to displaying the incoming video signal on the cathode-ray tube of an image-transfer converter whose scanning spot has a vertical cross-section identical with the interpolation law. Using the concept of an equivalent response as a function of vertical spatial frequency,[3] which is the Fourier transform of the line profile, it is then possible to calculate the response of various forms of interpolation to the range of vertical spatial frequencies[3] present in the input signal.

As discussed in Section 2.1, the cosine-squared interpolation law may be expressed in terms of a response, as a function of vertical spatial frequency:

$$g(f.T_I) = T_I \,.\, \frac{\sin 2\pi f T_I}{2\pi f T_I \,(1 - 4f^2 T_I^{\,2})} \tag{1}$$

This expression is zero when $f.T_I = 1{\cdot}0,\ 1{\cdot}5,\ 2{\cdot}0$ etc. and thus suppresses vertical-frequency components of $1/T_I$, $1{\cdot}5/T_I$, $2/T_I$ etc., a series of components which includes all the harmonics of input line frequency.

If zero response at output line frequency $1/T_0$ is also required, then the transform of the line profile must be zero when fT_I is equal to T_I/T_0 (for the case of 625- to 417-line conversion $T_I/T_0 = 417/625 = {}^2/3$). A zero can be introduced at the normalized frequency fT_I by adding to the original response a suitable proportion of a further response (i.e. a composite interpolation law) which is equal to the original response, but of opposite sign, when fT_I equals T_0/T_I. Such a response is the transform of a rectangular profile and may be written:

$$g_1(f.T_I) = 2T_I \frac{\sin 2\pi f T_I}{2\pi f T_I} \tag{6}$$

This expression has zeros when $2f.T_I = 1,\ 2,\ 3$ etc., so that the rejection of input line-frequency components is not affected. The zero at $f.T_I = 0{\cdot}5$ however reduces the combined response at half the input line frequency and somewhat impairs the vertical resolution. For values of $f.T_I$ between $0{\cdot}5$ and 1, $g_1(fT_I)$ is negative.

The requirement that the composite spectrum should have a zero at output line frequency ($f.T_I = {}^2/3$) is satisfied when:

$$(1 - k)\,.g(f.T_I) + k.g_1(f.T_I) = 0 \tag{7}$$

where $fT_I = {}^2/3$ (625 to 417 line conversion)

and k is a constant determining the proportions of the two spectra.

$$\therefore (1 - k).T_I \frac{\sin 2\pi f T_I}{2\pi f T_I (1 - 4f^2 T_I^2)} + k2T_I \frac{\sin 2\pi f T_I}{2\pi f T_I} = 0 \qquad (8)$$

whence $k = 0{\cdot}39$.

For composite interpolation therefore, the time functions representing the two spectra must be added together in the ratio $(1 - k)$ to k.

This determines the amount of d.c. to be added to the Hall multiplier current as mentioned in Section 2.2.

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